ANOMALOUS TEMPERATURES OVER THE ROCKY MOUNTAIN STATES OCTOBER 18–22, 1958

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1. INTRODUCTION

The weather feature discussed in this article is a reversal of the monthly normal temperature pattern that occurred during the period October 18–22, 1958. This brief period of low temperatures over the Rocky Mountain States was emphasized because it closely followed maximum temperatures of 80's and 90's near the Canadian Border. "A high of 97° was reported at Wagner, S. Dak. on the 15th . . . . Los Angeles recorded 104° on the 16th equaling the previous record high there for October" [1]. These abnormally high temperatures were quickly eliminated as a rapidly developing cyclone system brought cold air into the Pacific Northwest on the 18th and 19th.

Otherwise, October 1958 weather was generally uneventful with the Western States somewhat warmer and drier than normal while the eastern areas tended to be slightly cooler than normal. A complete discussion of these general features is given by Andrews [2] elsewhere in this issue.

2. GENERAL DISCUSSION

Figure 1 a and b picture the sea level isobars and the 500-mb. pattern as they existed on October 18. The 500-mb. chart is characteristic of the flow that prevailed for about one week prior to the period of this discussion. There was a pronounced long-wave trough in the vicinity of Ship P (50° N., 145° W.), a ridge over western United States, and a broad long-wave trough over eastern United States. Warm temperatures are generally associated with ridges and cold temperatures with troughs.

On October 17 a surface storm developed near Ship N (30° N., 140° W.) just east of the long-wave trough, deepened very rapidly, and on October 19 reached a minimum pressure of 962 mb. (fig. 2). As this Low moved northward into the Gulf of Alaska a portion of the cold air swept inland over the Pacific Northwest, but the main body of cold air remained well off shore behind the deepening storm. This feature was quite well marked in the thickness field, shown as dashed lines on the surface chart for October 18, figure 1a. Prognoses made by the National Weather Analysis Center (NAWAC) at this time indicated that the deep Low would move northward into the Gulf of Alaska, thence north-northwestward with a break-off coming inland over Canada to develop an Alberta Low.

This forecast demanded that the long-wave trough remain off shore and that only a short-wave trough move inland. Such was not the sequence of events. The surface Low did move into the Gulf of Alaska as forecast, but, instead of only a short-wave trough moving eastward through the Canadian Rockies, the entire long-wave trough moved eastward as developments in the western Pacific disturbed the equilibrium of the westerlies.

The meteorologist is regularly confronted with the problem of whether to forecast eastward progression of the long-wave pattern or to forecast a quasi-stationary long-wave pattern and migratory short waves. There does not seem to be a clear-cut answer for choosing one solution in preference to the other. Frequently, as seems to be pertinent in this situation, the clue should be sought upstream. Consequently, attention is directed to the western Pacific.

Near the tip of Kamchatka in figure 1b can be seen the beginnings of a new major storm system that brought about the change. On the surface chart (fig. 1a) only an east-west trough is visible. As the upper trough (fig. 1b) superimposed its vorticity upon the thermal field of the surface system, rapid cyclogenesis followed [3]. The wave with the 1008-mb. central pressure at 0000 GMT, October 18, became a mature occluded cyclone of 972 mb. near 49° N., 177° W. in 24 hours (fig. 2).

The failure to evaluate properly this spontaneous development directly influenced the prognosis for the west coast area. With such a development in the Pacific, the wavelength became too short to permit the long-wave trough to remain offshore of California. Consequently as the trough pushed eastward to adjust itself, the main body of cold air was forced inland and a rapid drop in temperature followed.

By 0000 GMT, October 19 (fig. 2), the deep mass of cold air had entered Washington and much of Oregon with an apparently insignificant flat wave located just off northern California. As the 500-mb. trough and associated vorticity moved to the California coast, it became superimposed on the "apparently insignificant" wave. Once again there was a sort of spontaneous action. At 0000 GMT, October 19, 12-hr. pressure change charts constructed at NAWAC indicated rising pressures from 120° W. to 155° W. longitude. This picture changed abruptly by 0600 GMT with weak 12-hr. pressure falls along the

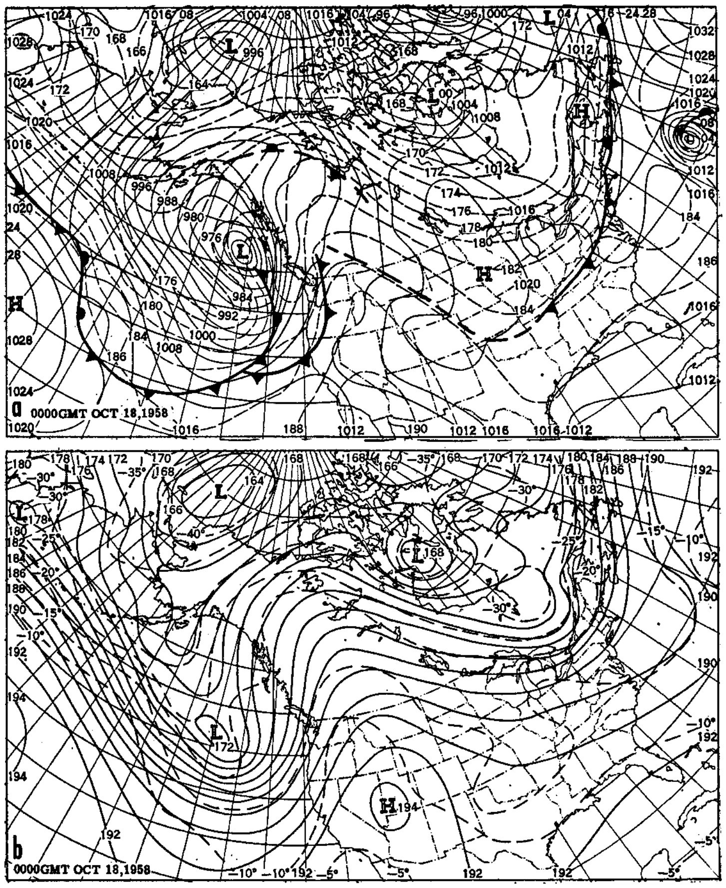

Figure 1.—0000 GMT, October 18, 1958. (a) Sea level isobars (solid lines) and 1000–500-mb. thickness contours (dashed lines) in hundreds of geopotential feet. (b) 500-mb. contours (solid) in hundreds of geopotential feet and isotherms (dashed) in °C.

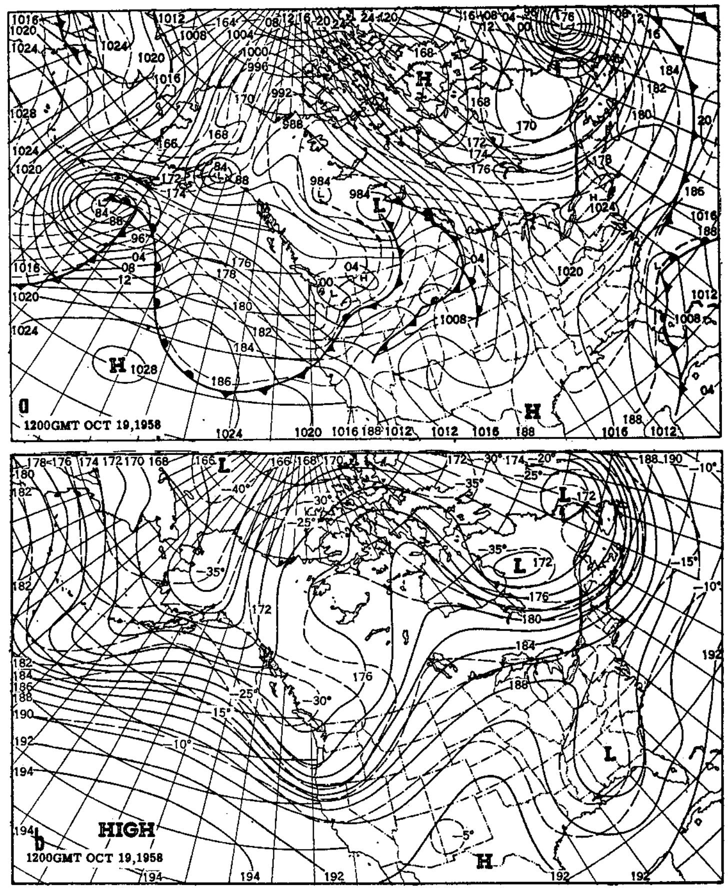

Figure 3.—1200 GMT, October 19, 1958. (a) Sea level isobars (solid lines) and 1000–500-mb. thickness contours (dashed lines) in hundreds of geopotential feet. (b) 500-mb. contours (solid) in hundreds of geopotential feet and isotherms (dashed) in °C.

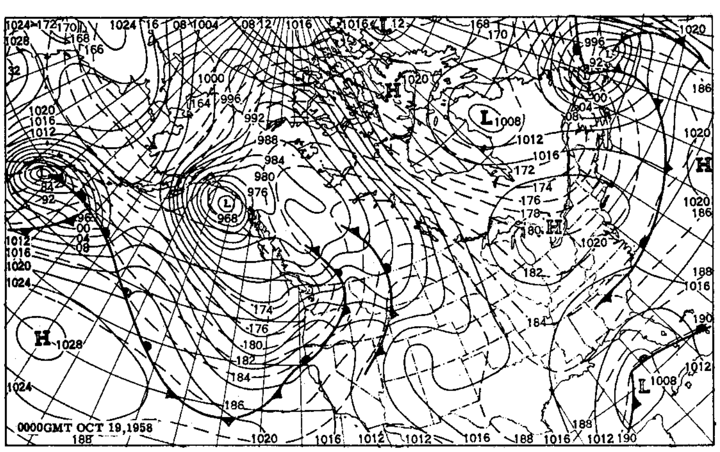

Figure 2.—0000 GMT, October 19, 1958. Sea level isobars (solid lines) and 1000–500-mb. thickness contours (dashed lines) in hundreds of geopotential feet.

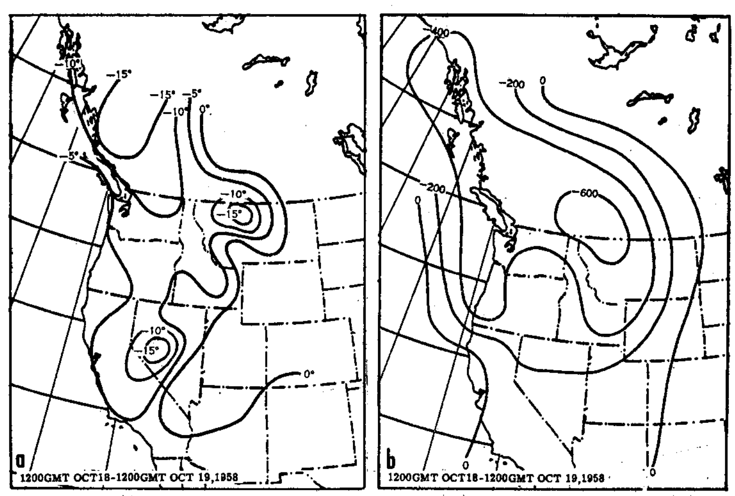

Figure 4.—24-hour change for period ending 1200 GMT, October 19, 1958. (a) Surface temperature. (b) 1000–500-mb. thickness.

Oregon-California border and 3-hr. tendencies of −2.5 mb. By 1200 GMT the weak 12-hr. falls had grown to 10-mb. falls and the 3-hr. tendencies to −5.0 mb., followed closely by 5.0-mb. rises. One might be tempted to insert a cold front in such a tendency field.

The surface chart and 1000–500-mb. thickness pattern for 1200 GMT, October 19 (fig. 3a), shows that such a solution is not in keeping with the density concept of fronts. Thickness lines may be considered as lines of equal density or of equal virtual temperature. Hence an examination of the thickness pattern shows a discontinuity of density gradient along the front as analyzed.

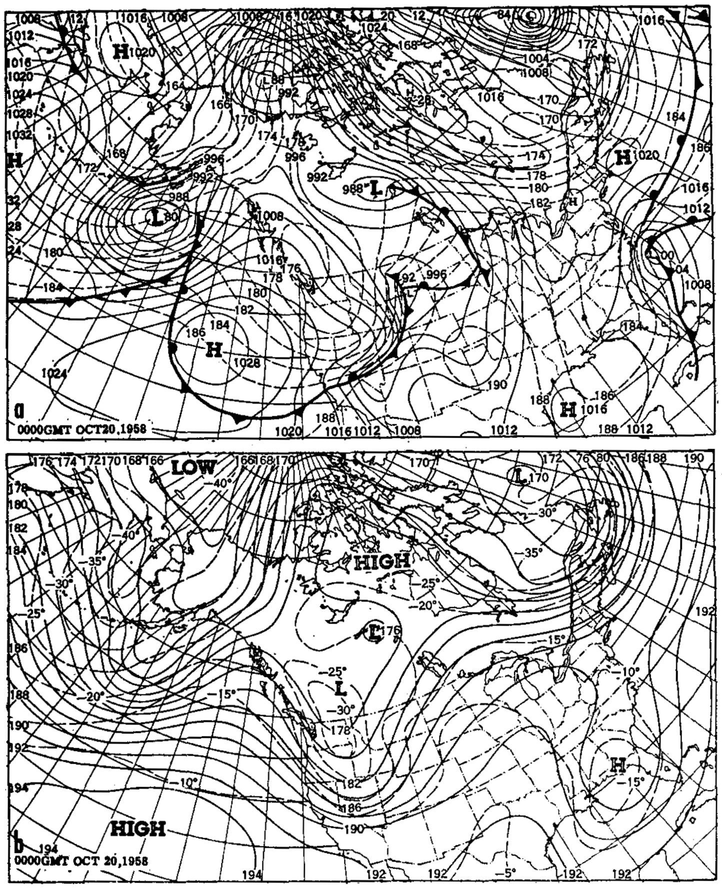

FIGURE 5.—0000 GMT, October 20, 1958. (a) Sea level isobars (solid lines) and 1000–500-mb. thickness contours (dashed lines) in hundreds of geopotential feet. (b) 500-mb. contours (solid) in hundreds of geopotential feet and isotherms (dashed) in °C.

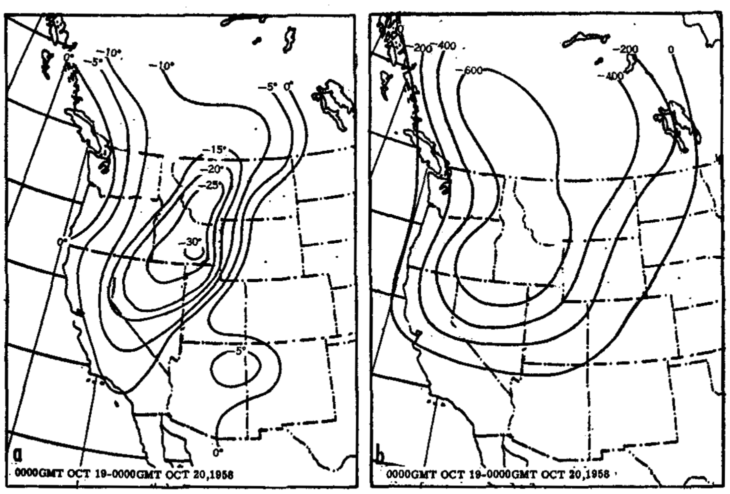

FIGURE 6.—24-hour change for period ending 0000 GMT, October 20, 1958. (a) Surface temperature. (b) 1000–500-mb. thickness.

If one insists on the classic development of an occlusion, this too is an impossible solution. The problem of what to call this sharp line in the tendency field frequently causes misunderstandings among meteorologists. Some meteorologists have attempted to solve the problem with their "trowal." When a surface Low develops well to

TABLE 1.—*Record temperature data*

Date/Type	Station	Temperature (° F.)	Record
Oct. 18/Max	Salt Lake City	83	New record high for so late in season.
	Ely	80	Do.
	Los Angeles	100	Do.
	San Diego	98	Do.
Oct. 19/Max	Pueblo	85	Equaled highest for so late in season.
	Great Falls	80	New record high for so late in season.
	Cheyenne	80	Do.
Oct. 20/Max	Pueblo	87	Do.
	Goodland	90	Do.
	Salt Lake City	82	Do.
Oct. 20/Min	Ely	13	New record low for so early in season.
Oct. 21/Min	Elko	8	New record low for so early in season and new low for October.
	Ely	8	New record low for so early in season.
Oct. 22/Max	Ely	53	Do.

the north of the surface wave and is embedded in the "cold" air, the classic occlusion process is not followed. Perhaps under these not unusual circumstances, "occlusion genesis" should be a recognized analysis

Figure 4a shows 24-hr. surface temperature changes that accompanied the development over the Pacific Northwest. The area of maximum change over Nevada was associated with the first small-scale penetration of cold air. It heralded the break of the heat wave of the previous few days that had sent temperatures to record highs so late in the season (table 1). The large area of maximum temperature change over Montana was the result of the deep cold air that moved inland with the long-wave trough.

During the 12 hours between 1200 GMT on the 19th and 0000 GMT on the 20th the storm reached maturity. The dome of cold air moved inland over southwestern Canada with axis tilted southeastward to Nevada. Associated surface temperature changes are indicated in figure 6a. The 24-hr. temperature falls encompassed much of the west coast, with the −20° F. isallotherm enclosing much of Montana, Idaho, and Nevada. The minimum temperature of 13° F. recorded at Ely, Nev., was the lowest on record so early in the season, only to be broken again on the 21st with 8° F.

Most of the cold air following the front was of apparent maritime polar origin, but with the surface Low moving into the Dakotas by 1200 GMT, October 20 (fig. 7a) continental polar air was introduced into the system. Apparently adding to the fury of the storm was the damming effect of the mountains as the easterly surface winds turned southward over Montana. During this period Glasgow recorded peak winds of 85 m. p. h. The effect of blocking in the upper pattern also entered the picture and the surface Low decelerated. From 0000 GMT, October 19 to 1200 GMT, October 20, the Low had moved at 33 kt. During the next 12 hours motion was negligible.

The blocking pattern is clearly seen in figures 5b, 7b, and 11b. In each chart a split in the strong westerly current is evident along the west coast with one portion going northeastward over the ridge in western Canada,

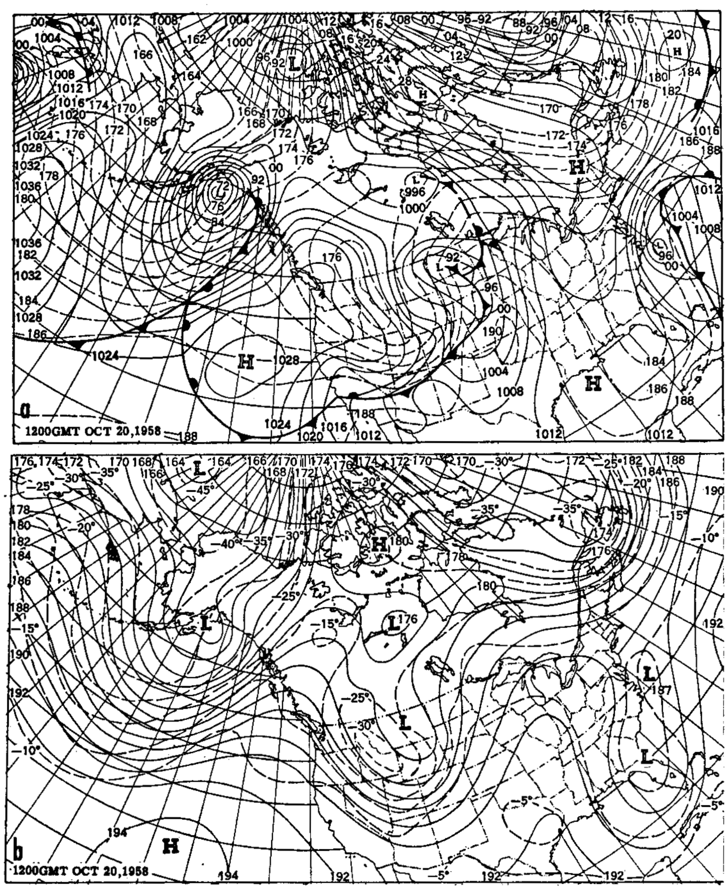

FIGURE 7.—1200 GMT, October 20, 1958. (a) Sea level isobars (solid lines) and 1000–500-mb. thickness contours (dashed lines) in hundreds of geopotential feet. (b) 500-mb. contours (solid) in hundreds of geopotential feet, isotherms (dashed) in °C.

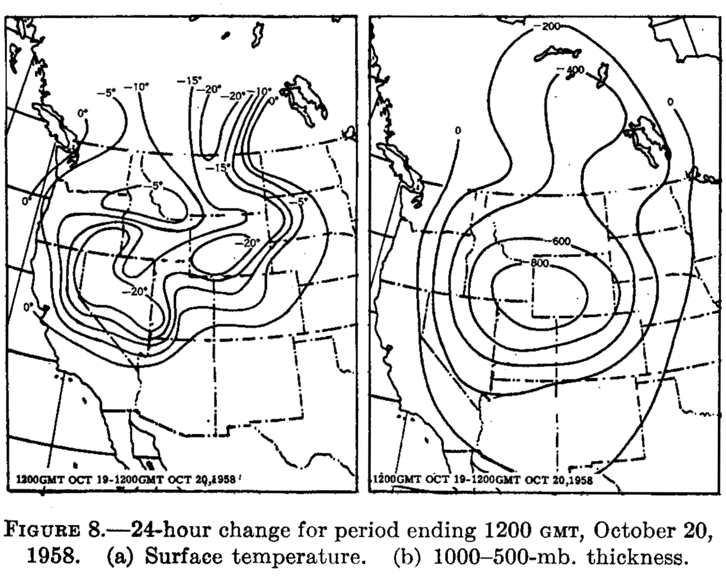

FIGURE 8.—24-hour change for period ending 1200 GMT, October 20, 1958. (a) Surface temperature. (b) 1000–500-mb. thickness.

and the other portion curving sharply eastward and southeastward around the Low over the Rockies.

The sharpness of the temperature change reached a maximum for the 24-hr. period ending at 0000 GMT, October 21 (fig. 10a). Just to the lee of the mountains, where record warm temperatures were experienced on October 19 and 20 (see table 1), a center of 24-hr. temperature drop of 35° was recorded over southeastern Montana.

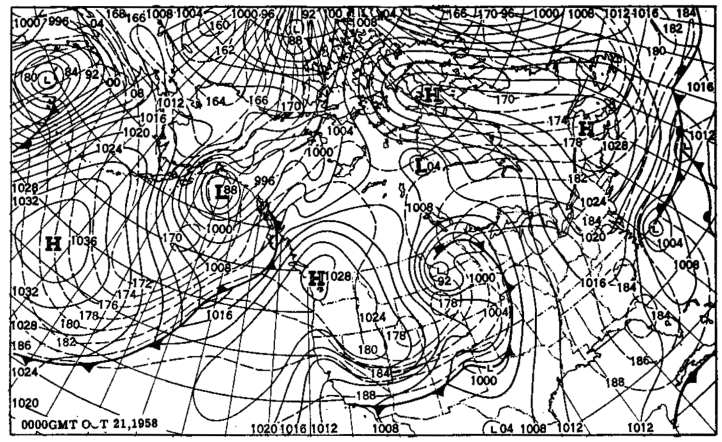

FIGURE 9.—0000 GMT, October 21, 1958. Sea level isobars (solid lines) and 1000–500-mb. thickness contours (dashed lines) in hundreds of geopotential feet.

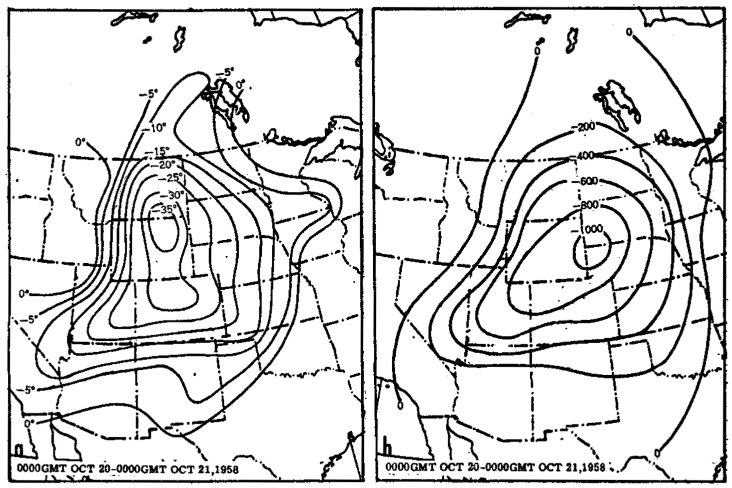

FIGURE 10.—24-hour change for period ending 0000 GMT October 21, 1958. (a) Surface temperature. (b) 1000–500-mb. thickness.

The passage of air over a given station can be analyzed with a time cross-section such as figure 13. The cold air over Seattle October 19, 20, and 21 is shown clearly as the isotherms drop down under the frontal surface. The slight ridge of warming in the isotherm pattern at 1200 GMT October 19 occurred as the wave moved northeastward well to the south of Seattle, as discussed.

To show more clearly the temperature change through a deep layer we have superimposed on figure 13 the 24-hr. temperature change. It is worthy of note that for every change of temperature in the troposphere there is a change of opposite sign in the stratosphere. Also the level of zero temperature change is found very close to the 250–300-mb. layer.

It appears from this chart and from a similar chart published in 1953 [4] that the temperature in the region 250–300 mb. is affected little by these major storms. A series of charts was prepared to point up the temperature

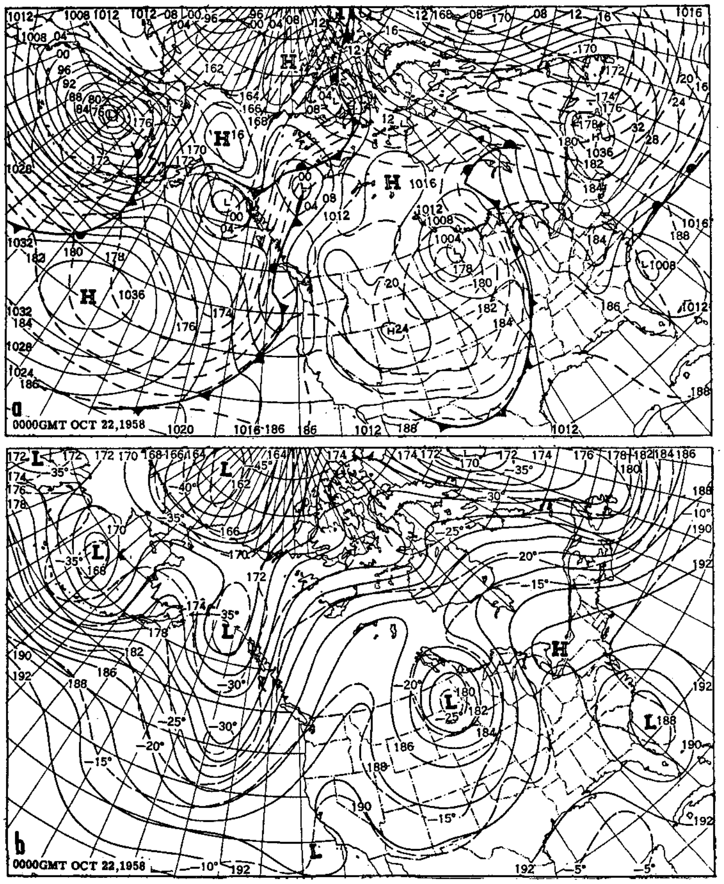

Figure 11.—0000 GMT, October 22, 1958. Sea level isobars (solid lines) and 1000–500-mb. thickness contours (dashed lines) in hundreds of geopotential feet. (b) 500-mb. contours (solid lines) in hundreds of geopotential feet, and isotherms (dashed) in °C.

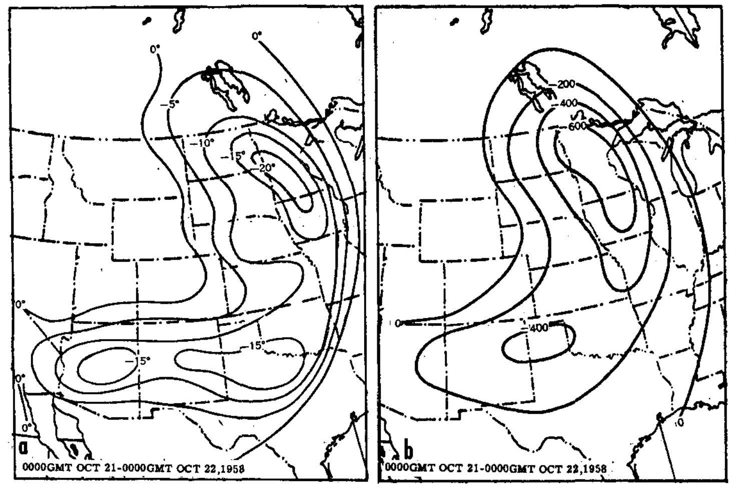

Figure 12.—24-hour change for period ending 0000 GMT, October 22, 1958. (a) Surface temperature. (b) 1000–500-mb. thickness.

change—thickness change relationship in this situation. A discussion of this relationship follows.

3. SURFACE TEMPERATURE AND THICKNESS CHANGE

The variability of polar air temperature fields when moving is rather well known, and most weathermen are aware of the processes that render surface temperature readings nonrepresentative or nonconservative. For example, a study of trajectories of air and vertical motions over surfaces can be made in a more or less subjective manner, and the results of variations in the stability conditions handled reasonably. However, because the cold outbreak which is presented here moved over the mountains of the Northwest, no attempt has been made to trace trajectories in a detailed manner, but rather to discuss and compare the overall relationships of the 24-hr. changes of the surface temperature and of the 1000–500-mb. thickness. These changes are the basic tools for NAWAC maxima and minima temperature forecasting.

In general, the forecast of degree of change in maximum or minimum temperatures is determined from a relationship between the 1000–500-mb. thickness change and surface temperature change.

For example: a change of ±200 ft. in the 1000–500-mb. thickness represents a change of ±5° F. in the mean virtual temperature of this layer. If there is no change in the shape of the temperature sounding, i. e., no change in stability, then this ±5° F. change also represents the change at the surface [5], or for that matter at any other level within this layer. Thus, from the forecast 1000–500-mb. thickness, the first step in reaching the surface temperature change is quantitatively determined. These changes are then adjusted for expected cloud and/or precipitation areas or for other large-scale areas where stability changes may take place.

On the basis of the aforementioned procedures, 24-hr. 1000–500-mb. thickness change and 24-hr. surface temperature change charts were developed from NAWAC 1000–500-mb. thickness charts and regular surface facsimile maps. For the most part, the following discussion is concerned with the relationship of the 24-hr. thickness pattern to the 24-hr. surface temperature change with regard to: shape of the pattern, center of greatest change, gradients of patterns, and numerical magnitudes.

Figure 4 a and b shows the 24-hr. temperature and thickness changes ending at 1200 GMT, October 19. These two patterns show a good relationship in their general pattern and corresponding minimum thickness and minimum temperature change centers in the Pacific Northwest. However, the negative surface temperature change over Nevada does not have a good counterpart in the thickness field. Insufficient data in that area preclude an exact determination of the cause of the lack of agreement, but development of strong surface inversions by radiation is the probable cause.

From figure 6 a and b, it is evident that the polar air had moved over the Pacific Northwest to establish well defined 24-hr. temperature and thickness change patterns. The two patterns closely match. The center of cold air at the surface was in the Pocatello, Idaho area and was elongated north-northeast—south-southwest, whereas the

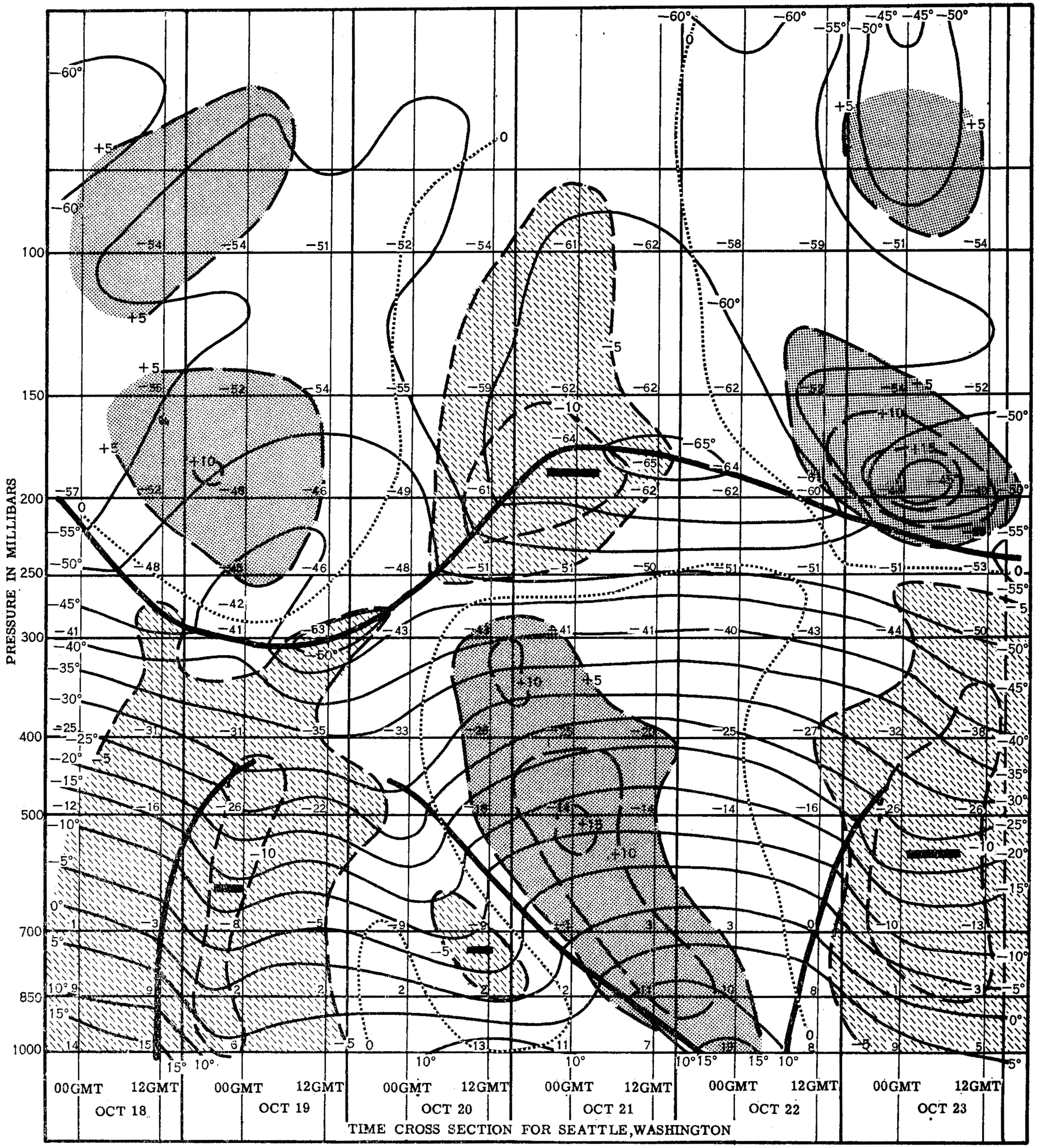

FIGURE 13.—Time cross-section for Seattle, Wash., October 18 to 23, 1958. The plotted temperatures are analyzed by thin solid lines, with fronts and tropopause shown by heavy lines. Dashed lines show 24-hr. temperature change with zero change line dotted.

center of the thickness was in the Boise, Idaho area and was elongated in the same direction as the temperature change field. Because the coldest air aloft appears to have moved from the northwest to a position over eastern Washington at 0000 GMT, October 20 (figs. 3b and 5b), this tilt of 24-hr. surface temperature change and thickness change centers should be expected. Positions of pattern gradients of both charts are in good agreement. The small deviation over northeastern Arizona could be attributed to local orographic effects.

The general patterns of figures 8a and 8b show rather good agreement. The center of greatest 24-hr. temperature change was displaced to the southeast of the center of 24-hr. thickness change. Figure 7b indicates that the center of cold air aloft was still northwest of the cold air at the surface; thus the tilt of the thickness change and surface temperature change centers existed. Visual checks of the gradient in relation to each pattern point to fair agreement except in Washington, Idaho, and Montana. The fact that the surface temperature change pattern lay crosswise of the mountain chain could account for the irregularities. The $-5°$ change (fig. 8a) over northern Idaho could be attributed to increasing stability suggested by the negative vertical motion as portrayed by the vertical motion chart prepared by Joint Numerical Weather Prediction Unit for 1200 GMT, October 20 (not shown).

In figure 10 a and b, the general areas of 24-hr. temperature change and 24-hr. thickness change, more or less bracket each other. The centers were by then tilted in the opposite sense. That the coldest air aloft was to the southeast and southwest was evident from the thickness pattern associated with the surface map (fig. 9), and the 500-mb. map for 0000 GMT, October 21 (not shown here). Once again, gradients were comparable in relation to position.

Figure 12 a and b, 24 hours after figure 10, shows that the cold air had moved over the western central Plains. The general patterns of the temperature and thickness change were again very similar and the centers were more closely associated. Figure 11 a and b shows that the cold air aloft had completely encompassed the closed Low at that level, and the axis of the Low tilted very little between the surface and 500 mb. This suggests that good agreement should have existed between the two patterns at this time. Gradients of the patterns were also in good agreement with respect to position.

In summary, it can be said that for the two patterns presented here, i. e., 24-hr. surface temperature change and 24-hr. 1000–500-mb. thickness change: (1) there was good agreement in general pattern of negative thickness lines and negative surface temperature change; (2) centers were tilted, or out of phase, with the same tilt as the cold dome itself; and (3) gradients of corresponding thickness and temperature change patterns were approximately in the same geometric position in each pattern.

Consideration of magnitudes of the gradients in this series of charts, shows that at the forward edge of the patterns the surface gradients of the 24-hr. temperature change were greater than the accompanying gradients of the 1000–500-mb. thickness change. For example, in figure 6, the gradient difference that stretched to the southeast of the Salt Lake City area could be attributed to orographic effects whereas the gradient differences that existed in eastern Iowa (see fig. 12) could not be interpreted that way. The gradient of temperature change was approximately 15° F. per 2 degrees latitude, and the gradient of thickness change was 400 ft. per 2 degrees latitude in that area. The above could be accomplished (within restrictions of $\pm 5°$ F. $= \pm 200$ ft. thickness change) by the mean virtual temperature decreasing at a slower rate, toward colder air at the surface, than the surface temperature decreased. This, in effect, is what occurred in the Iowa area because the process took place through a sloping frontal zone. The gradients of surface temperature change were more intense because they represented the complete change across a frontal zone. The overlying gradients of the mean virtual temperature change were weaker because they represented an average of the strong temperature gradients in the cold air (beneath the frontal surface) and the quasi-uniform temperature field in the warm air (above the frontal surface).

Also the magnitudes of surface centers were greater than indicated by $\pm 5°$ F. $= \pm 200$ ft. in thickness change. Of course, the relations are modified by temperature inversions, loss or gain of moisture, insolation, orographic effects, and other causes that can change the stability.

4. CONCLUSION

Because the system off the west coast deepened more than was anticipated, the temperature forecasts, which are tied directly to the surface and upper air forecasts, suffered accordingly. Recognition of the differences encountered in the 1000–500-mb. thickness and surface temperature relationship may produce more precise forecasts.

ACKNOWLEDGMENTS

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